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# Applications of Net Radiometer Measurements to Short-Range Fog and Stratus Forecasting at Los Angeles

by

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Editor's Note:

The study on which this report is based was performed during Mr. Thomas' tour at the Regional Headquarters as a summer trainee, June to September 1966. Mr. Thomas had completed his junior year in the Honors program at Michigan State University at the start of this summer tour of duty. His major is Physics.

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# APPLICATIONS OF NET RADIATION MEASUREMENTS TO SHORT-RANGE FOG AND STRATUS FORECASTING AT LOS ANGELES

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## I - INTRODUCTION

In June 1965 a Thornthwaite Miniature Net Radiometer was placed in operation at the Weather Bureau Airport Station in Los Angeles for use in short-range fog and stratus forecasting. It was believed that the instrument might be used in either of two ways: a) to measure radiative cooling and heating which could then be projected to determine the probability and timing of fog formation or dissipation; or b) to detect changes in temperature and moisture in the atmosphere over and above those observed with current surface measurements.

## II - INSTRUMENTATION

The sensor is a small disk containing a thermopile transducer and mounted parallel to the ground. The upper and lower surfaces of the disk are finished with flat black paint. The transducer is enclosed in two hemispherical polyethylene windows inflated with dry air. The manufacturer states that the instrument gives essentially uniform absorption of both long- and short-wave radiation, including all significant solar, terrestrial, and atmospheric radiation. Response varies with the cosine of the angle of incidence relative to the vertical axis of the sensor. The temperature difference between the upper and lower surfaces of the transducer is essentially proportional to the net radiation. This temperature difference is sensed by the thermopile and the output is used to drive a General Electric recorder.

The system is not adequate to provide high-quality, reliable data. The Thornthwaite radiometer has a limited sensitivity for this type of study so that important changes are often very difficult to detect. Signal quality is not good enough to permit further amplification. The instrument has frequently been out of operation, and much of the data is not usable because of unexplained discontinuities and irregularities. The zero setting is unreliable, both because of difficulties with the recorder and because of dirt on the upper window of the sensor. Large errors could generally be eliminated, but smaller discrepancies were almost impossible to detect.

There was no site available for mounting the instrument which offered both a representative surface and easy access for maintenance. Originally, the sensor was installed on the roof above the Weather Bureau office; but since radiation and reflection from the building were believed to be important, it was moved in March 1966 to a location between the two main runways. The earth and grass under the sensor were more representative than the roof; however, because of the increased distance to the recorder (about 2500 feet) and the lack of maintenance, the later data appears to be inferior to that from the original site.

## III - THEORY

Net Radiation ($R_n$) consists of downward short-wave ($S_d$), downward long-wave ($L_d$), upward short-wave ($S_u$), and upward long-wave radiation ($L_u$). Radiation toward the earth's surface is arbitrarily taken as positive so that the net flux of radiative energy is:

$$R_n = S_d + L_d - (S_u + L_u)$$

The direct and scattered solar radiation ($S_d$) generally dominates the day-time net radiation. Values of $S_d$ can be over 90 langleys per hour at noon on a clear summer day. Under a winter overcast, the noon value is at times less than 10 ly/hr., and the early morning and late afternoon readings are nearly zero. From sunrise to sunset the changes in short-wave radiation obscure the more gradual variations in long-wave radiation. The upward short-wave flux ($S_u$) is reflected solar radiation and, for a given surface, should be an almost constant fraction of $S_d$.

The terrestrial radiation is determined by the ground surface temperature and by the condition of the surface. Actually, since the radiometer is mounted one meter above the surface, $L_u$ also includes upward radiation from a shallow layer of air. Because air absorbs and radiates strongly in the long wavelengths, the effect may be considerable. Ground temperature and air temperature at this low level are highly correlated and this study is not concerned with radiation values exactly at surface level; therefore, $L_u$ was assumed on a given day or night to be a function only of ground surface temperature. Values of $L_u$ ordinarily reach a maximum in the after-noon (typically about 35 ly/hr.) and decline during the night. This decline in $L_u$ is particularly balanced by a decrease in $L_d$ as the air temperature decreases, so the nighttime increase in $R_n$ is seldom more than 2 or 3 ly/hr. and is concentrated in the first few hours of darkness.

The downward long-wave radiation, $L_d$, is from water vapor and $CO_2$ in the atmosphere and from clouds. With clear skies, $L_d$ is a function of humidity and air temperature, principally in the lower layers of the atmosphere. Swinbank (1) developed an empirical formula for $L_d$ using only the surface temperature and found very good agreement with observations. Myers (2) has calculated that a change in humidity from 75% to 100% produces a variation in $L_d$ of less than 5% (or about 1 ly/hr). Myers also asserts that over half of the long-wave radiation reaching the earth originates in the lowest 2mb., and about 70% originates in the lowest 10mb. Generally, any changes in humidity or air temperature detected by the radiometer should be obvious from conventional surface observations.

With clear skies $L_d$ is usually between 20 and 25 langleys per hour. Smoke, dust, and dry haze are not important influences; however, both Myers and Swinbank mention that a low inversion can make values of $L_d$ considerably greater than the surface temperature would indicate.

Clouds, unless very thin, radiate essentially as black bodies. With a low overcast or heavy fog, $L_d$ is approximately equal to $L_u$ (about 30 ly/hr.), and at night the net radiation is near zero. On several nights the net radiometer has recorded values considerably above zero. Perhaps the instrument was faulty, but it is also possible that the effect was real since condensed water in the inversion can be warmer than the surface. Values of $L_d$ decrease to the clear sky value as the ceiling height increases. Nighttime clouds, up to at least 15,000 feet, can have an important effect.

## IV - POSSIBLE APPLICATIONS

A direct application of the net radiometer to fog forecasting would be to measure nighttime cooling to determine if the temperature will decrease to the dew point, causing formation of radiation fog. Practically, the record of radiative heat loss is not available until after cooling has taken place, but perhaps the evening radiometer reading could be projected for the remainder of the night. A major complication is that $R_n$ as measured by an instrument one meter above the ground (or above the roof of a building) is not necessarily the same as the net flux of energy out of the layer of air being cooled. Since heat is generally convected downward during the period of nocturnal cooling, the net loss of heat at the surface is much less than that indicated by the radiometer. Also each layer of air absorbs much of the long-wave radiation from above and below and then reradiates at its own temperature; therefore, $R_n$ varies with height as described by James et al (3), and a surface radiometer cannot give directly the total loss of heat as indicated by the afternoon and morning raobs. Since $R_n$ is itself determined primarily by cloud cover and surface temperature which are already included in making the forecasts, net radiometers probably will not significantly improve the predictions. If the relationship between surface radiation and nighttime cooling were found to be simple yet dependable, net radiometers would be valuable in simplifying the forecast procedure by integrating the various factors to give one definite value for the rate of cooling. Because of the poor quality of the available net radiation data and the lack of occurrence of purely radiation fogs during the period of satisfactory instrument operation, no attempt was made in this study to devise and test such a scheme.

The radiometer would be useful in predicting the breaking of fog or stratus if it provided some indication of cloud density not available from measurements of ceiling height and aircraft reports of cloud tops. Upward radiation, $S_u$ and $L_u$ , provides no useful information about clouds, and $L_d$ seems unaffected by any changes above the cloud base. Downward solar radiation is a function of cloud density, but the Los Angeles station has an Eppley solar radiometer which provides a record of $S_d$ superior to that obtained from the net radiometer.

The problems of using the net radiometer to forecast radiation fog formation also apply to forecasting the breaking of fog or stratus by measuring the energy available for heating, as $R_n$ is not actually a direct measure of available energy.

In addition with a heavy fog or low stratus, $L_d$ and $L_u$ nearly balance so:

$$R_n = S_d - S_u$$

The net radiometer readings are less than the Eppley readings on such mornings by 15% to 25%, corresponding to the albedo of the normally dry surface. Any calculations of morning heating could use the Eppley radiometer data rather than the surface net radiation simply by including a correction for this reflection.

The most promising application of the net radiometer to fog forecasting is in detecting changing conditions which precede the onset of fog. Either a low inversion or the presence of condensed moisture increases $L_d$, and at night makes $R_n$ less negative. Fog is often associated with a low inversion, and it is quite possible that condensation begins considerably before the actual onset of fog, especially with the abundant nuclei characteristic of Los Angeles. The net radiometer might, therefore, provide some warning of fog or low stratus. Such a method would be limited to clear nights, since solar radiation or radiation from clouds obscures the changes in $L_d$ associated with the inversion or unobserved condensation.

## V - RESULTS

In the data* there are several cases in which the net radiation on clear nights was considerably above the usual levels. When the morning raob indicated the inversion to be near the surface, the radiometer trace for the preceding night would generally reach a minimum value soon after sunset and then rise to the first line on the chart below the zero line (about -3 ly/hr). If the air mass was not near saturation and if no fog or clouds formed, the trace remained at this line until sunrise. In some instances the trace continued to rise above -3 ly/hr., although no clouds were reported. The rises were always associated with high humidity and generally with decreasing visibility. Any value above -3 ly/hr. which could not be explained by reported clouds was assumed to indicate unobserved condensed moisture and to be a warning of fog.

Figures 1A and 1B show the net radiometer trace from the night of October 3-4, 1965. The radiation first rose above the warning level about midnight, then continued to rise until the onset of fog at 0330 PST. At the time of the first warning, dew point depression was 6°F and visibility was 8 miles. In this instance the fog was advected from the coast rather than forming at the airport, but the net radiometer was still able to give a warning of 3-1/2 hours.

Figures 2A and 2B show a similar warning from November 4-5, 1965. The first warning was at 0045 PST and the fog arrived at 0515. Again the fog was advected from the coast. Figure 3 shows a distinct warning of fog; however, the visibility was never less than 4 miles. No clouds were reported during the night or early morning. Even in this unsuccessful instance, the humidity was high enough that condensation might have taken place.



* For period June 1965 through July 1966

The rises in net radiation are highly correlated with decreasing dew point depression and decreasing visibility as illustrated in Figures 4 and 5. In none of the cases did the radiometer reveal a general trend not apparent from other measurements; however, on some occasions the radiometer gave a distinct warning while dew point depression and visibility indicators were still inconclusive.

The net radiometer trace rose above the warning level on 9 occasions which could not be associated with concurrent reports of clouds or fog. Seven of these warnings were followed by fog within 6 hours. The minimum visibilities which followed the 9 warnings are shown in Table 1.

TABLE 1

| Minimum Visibility | Number of Cases |
|---|---|
| 0 - 1/2 mile | 5 |
| 5/8 - 1 mile | 2 |
| 1-1/8 - 3 miles | 0 |
| 4 miles or more | 2 |

During the period that the instrument was operating satisfactorily, there were 14 cases of fog (minimum visibility 1 mile or less) which formed at night without important clouds. Generally, "high, thin" and some lower scattered clouds could be neglected, but the actual determination of which clouds were "important" was made from the radiometer trace itself. Figure 6 shows the warnings given by the net radiometer in the 14 cases. For 7 of the 14 cases, the radiometer trace rose above the warning level at least one hour before the onset of fog. Time of onset was determined from the radiometer traces as the first reading at or above zero, and verified by the hourly and special observations. Frequently the minimum visibility was not reached until several hours after fog onset. On November 7, 1965, onset was actually the arrival of stratus at 1000 feet, 1-1/2 hours after the first warning; the visibility simultaneously decreased from 1-1/2 miles to 1 mile. The amount of warning varied from 1-1/2 hours to 5 hours, averaging about 3 hours. There is apparently no way of using the warnings to predict the exact time of fog onset or the intensity.

## VI - CONCLUSIONS

During the day the net radiometer is of little use in detecting changes in the atmosphere since $S_d$, which obscures any variations in the other three components, is already measured by an Eppley solar radiometer. On cloudy nights the net radiometer provides some indication of cloud cover and ceiling height but is far less accurate than human observations or ceilometer measurements.

Surface net radiometers cannot be used to give a direct record of radiative cooling associated with radiation fog. The evening measurements might be useful in a simplified scheme to predict minimum temperatures, radiation fog, and frost but probably would not significantly improve forecasts at most stations, especially those where advection is as important as at Los Angeles.

Calculations of morning heating associated with the breaking of fog or stratus would probably be just as accurate if based on total solar radiation measurements or charts of incident insolation rather than surface net radiation.

The net radiometer is apparently able to qualitatively indicate a low inversion or the presence of liquid water, conditions which frequently precede the formation of fog. The instrument is not able to provide a quantitative measure of any of the atmospheric variables, and for fog forecasting it is useless during the day or under cloudy skies. The technique described in this study warned of only half the fogs which occurred under suitable conditions, and the successful warnings were always accompanied by decreasing dew point depression and decreasing visibility. The data apparently cannot be used to forecast the exact time of fog onset. Although a better instrument, better exposure and a longer period of record might reveal more useful relationships, the net radiometer does not appear to be of significant value in fog forecasting at Los Angeles.

Although net radiometer data are of little use to fog forecasting, the results of this study indicate that more specialized radiation sensors would be useful. A radiometer measuring just $L_d$, or perhaps selected narrow bands within $L_d$, should be much better than the net radiometer for detecting condensed moisture. Most of the atmospheric radiation originates very near the surface; however, in the atmospheric "windows" the intensity is a function of both temperature and humidity at higher levels. Perhaps by selecting a band with weak absorption by water vapor and little $CO_2$ absorption, a radiometer could indicate changes in humidity aloft. Similarly, since $CO_2$ content in the air is nearly constant, a band with little absorption by water vapor and moderate absorption by $CO_2$ might be used to measure temperature changes aloft. The instrument might even be developed to the point of giving a continuous record of the inversion height at stations such as Los Angeles. Several proposals for the use of specialized infrared sensors are discussed by House and Blankenship (4).

## VII - ACKNOWLEDGMENTS

The writer is indebted to G. W. Kalstrom, J. H. Aldrich and the staff of the Weather Bureau Airport Station, Los Angeles for their work in supplying the radiation data and observations used in this study and for their aid and advice during his visit to the station. Comments by L. W. Snellman, P. Williams, Jr., and C. L. Glenn of the Weather Bureau Western Region Headquarters during preparation of this paper were very much appreciated.

## VIII - REFERENCES


1. W. C. Swinbank, "Long Wave Radiation from Clear Skies", Quarterly Journal of the Royal Meteorological Society, Vol. 89, July 1963, pp. 339-348.

2. V. A. Myers, "Infrared Radiation from Air to Underlying Surface", ESSA Technical Note 44-Hydro-1, Washington, D. C., May 1966.

3. D. G. James, D. W. S. Limbert, and J. C. McDougall, "A Radiometer Sonde", The Meteorological Magazine, Vol. 95, June 1966, pp. 161-174.

4. F. B. House and J. R. Blankenship, "Applications of Infrared Measurements in Meteorology", Technical Report 157, Air Weather Service (MATS), United States Air Force, Scott AFB, Illinois, June 1961.

October 3-4, 1965

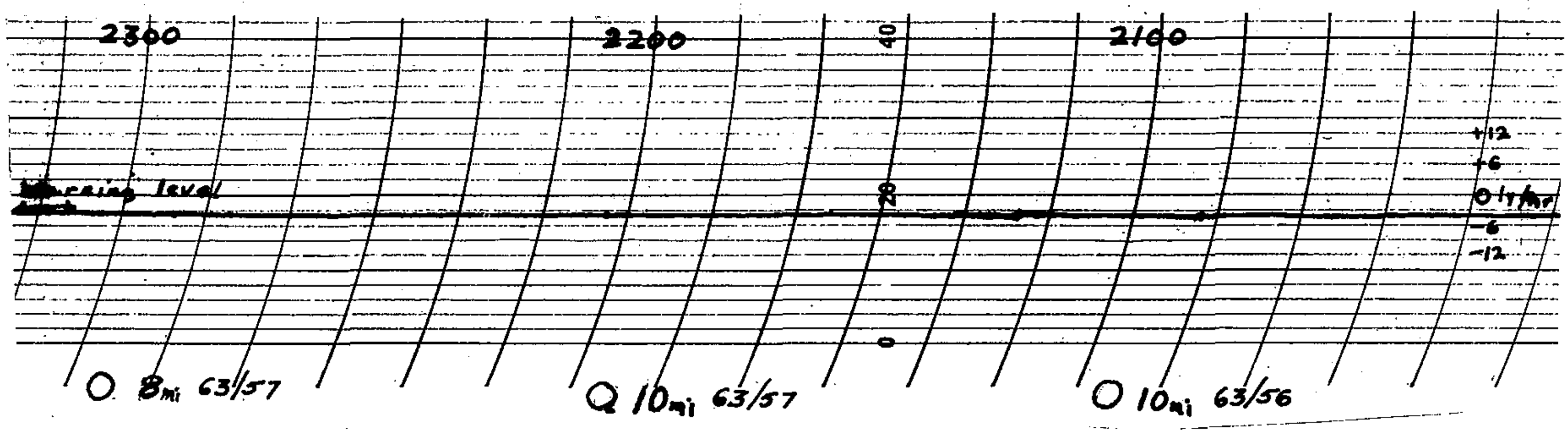


Figure 1A - Net radiometer trace for Los Angeles (International Airport) with hourly observations of cloud cover, visibility (in miles) and temperature and dew point (in degrees Fahrenheit). Times are PST. Trace is continued in Figure 1B.

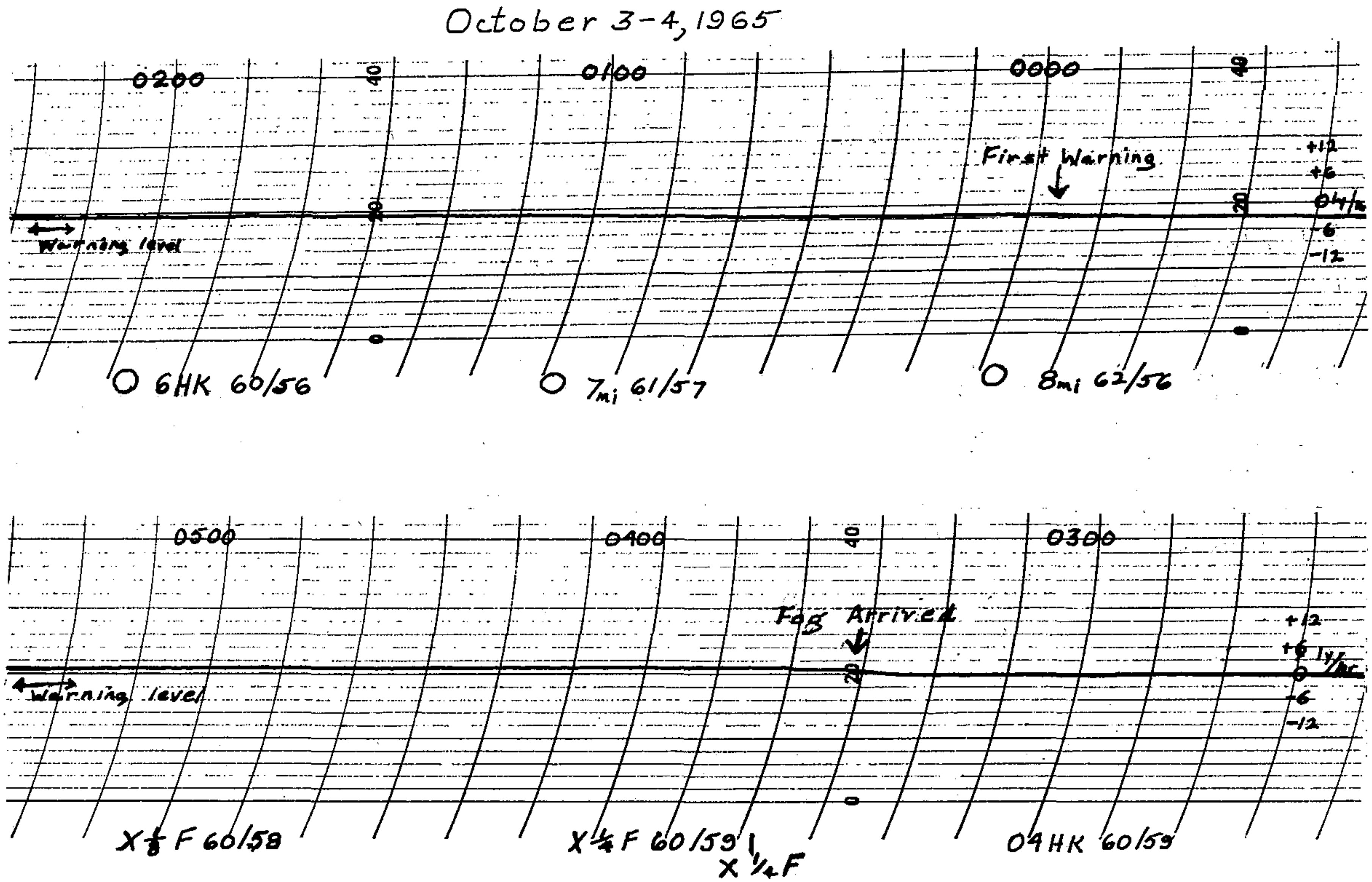


Figure 1B - Net radiometer trace (See Figure 1A for Legend) October 3-4, 1965

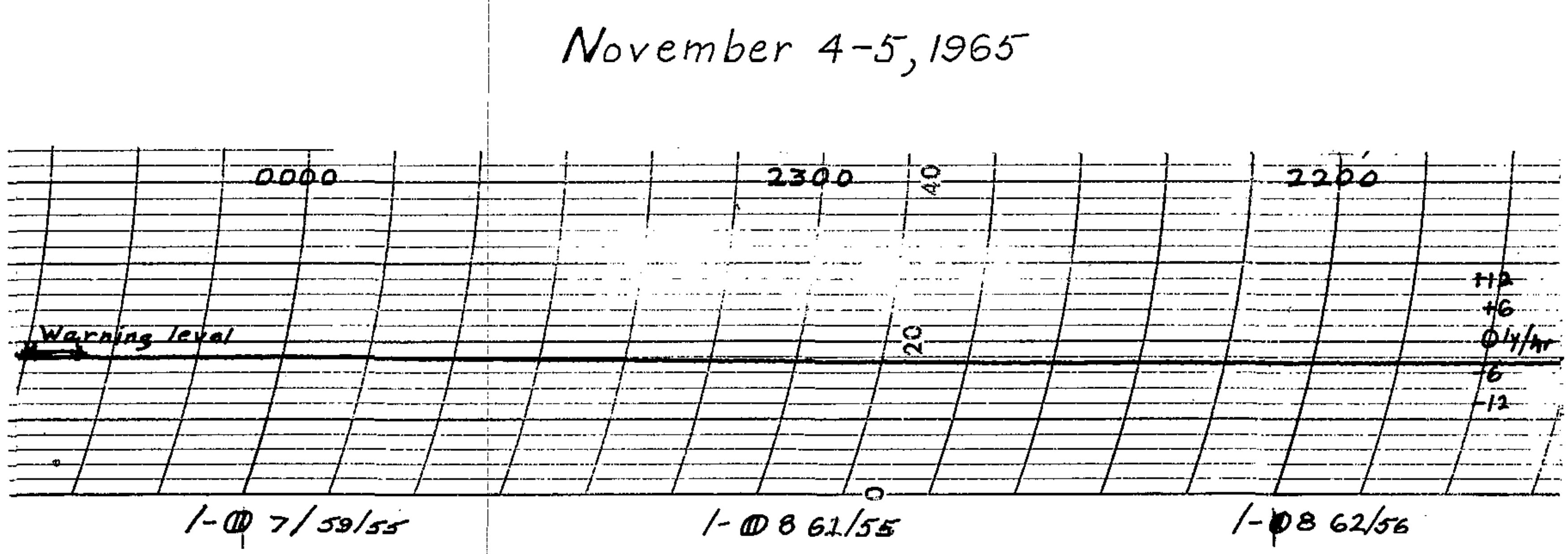


Figure 2A - Net radiometer trace for Los Angeles, November 4-5, 1965 (see figure 1A for legend). The trace continued in figure 2B.

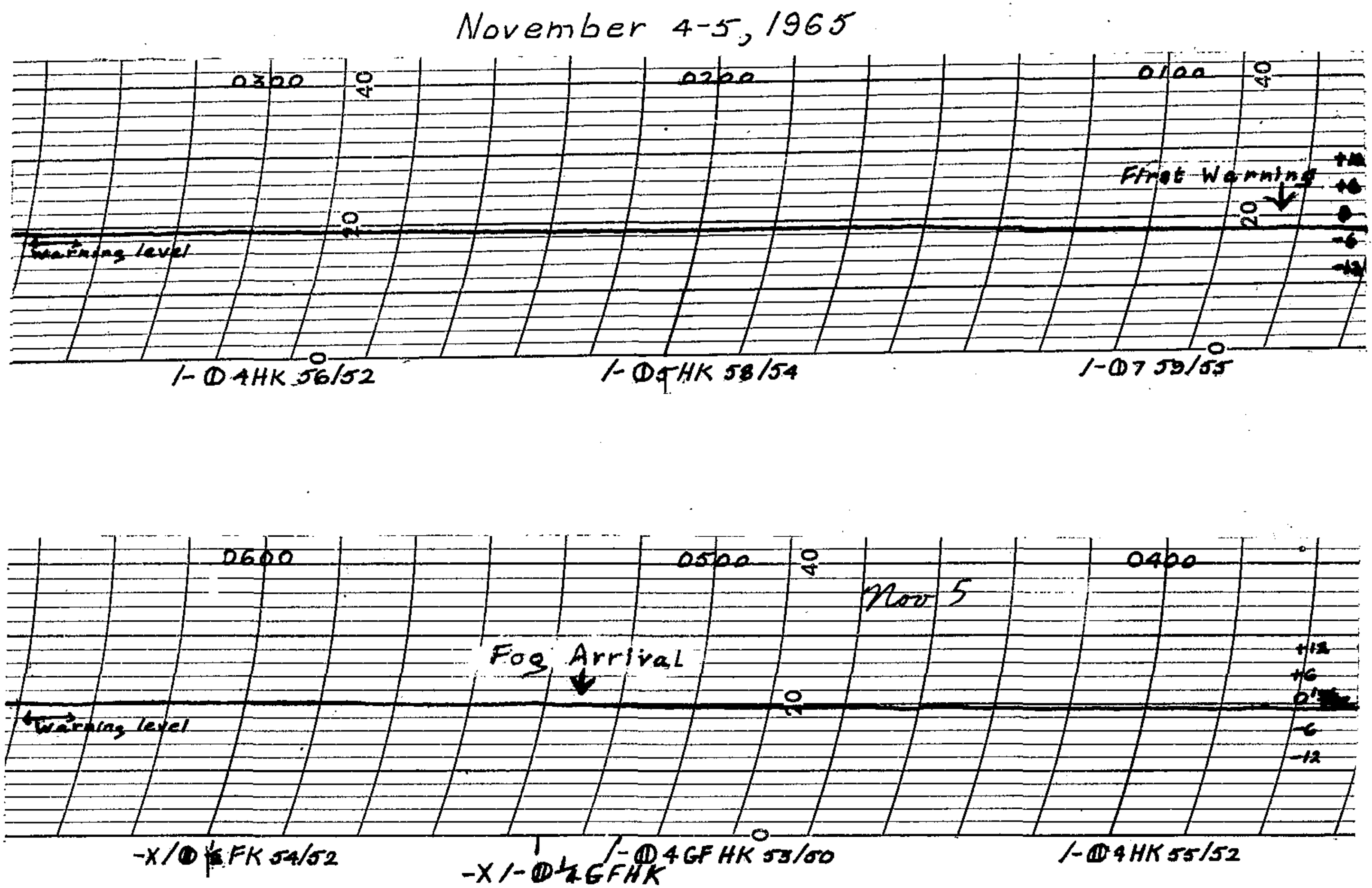


Figure 2B - Net radiometer trace for Los Angeles, November 4-5, 1966. See Figure 1A for Legend.

December 15, 1965
(no fog formed)

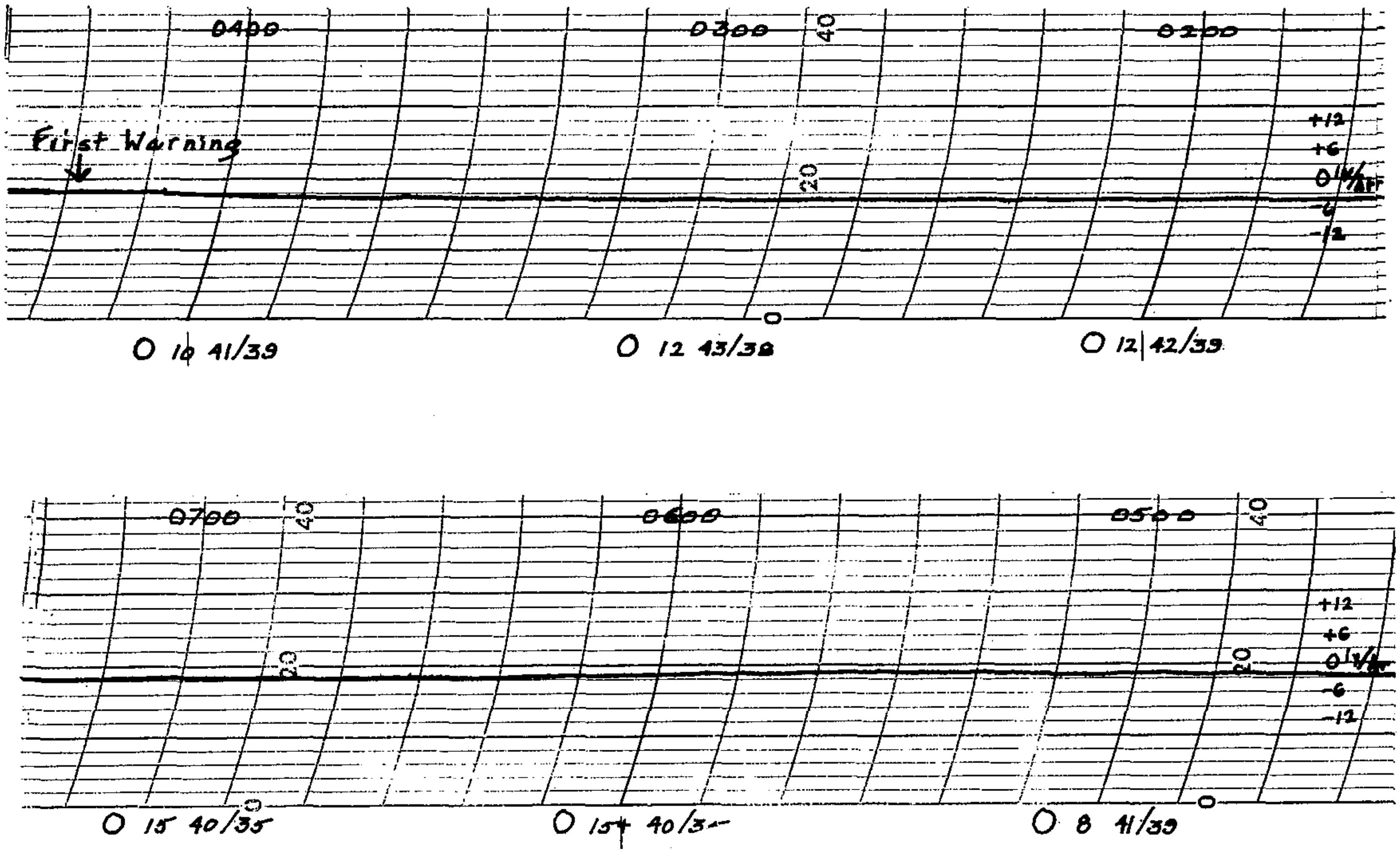


Figure 3 - Net radiometer trace for Los Angeles, December 15, 1965. (See Figure 1A for Legend.)

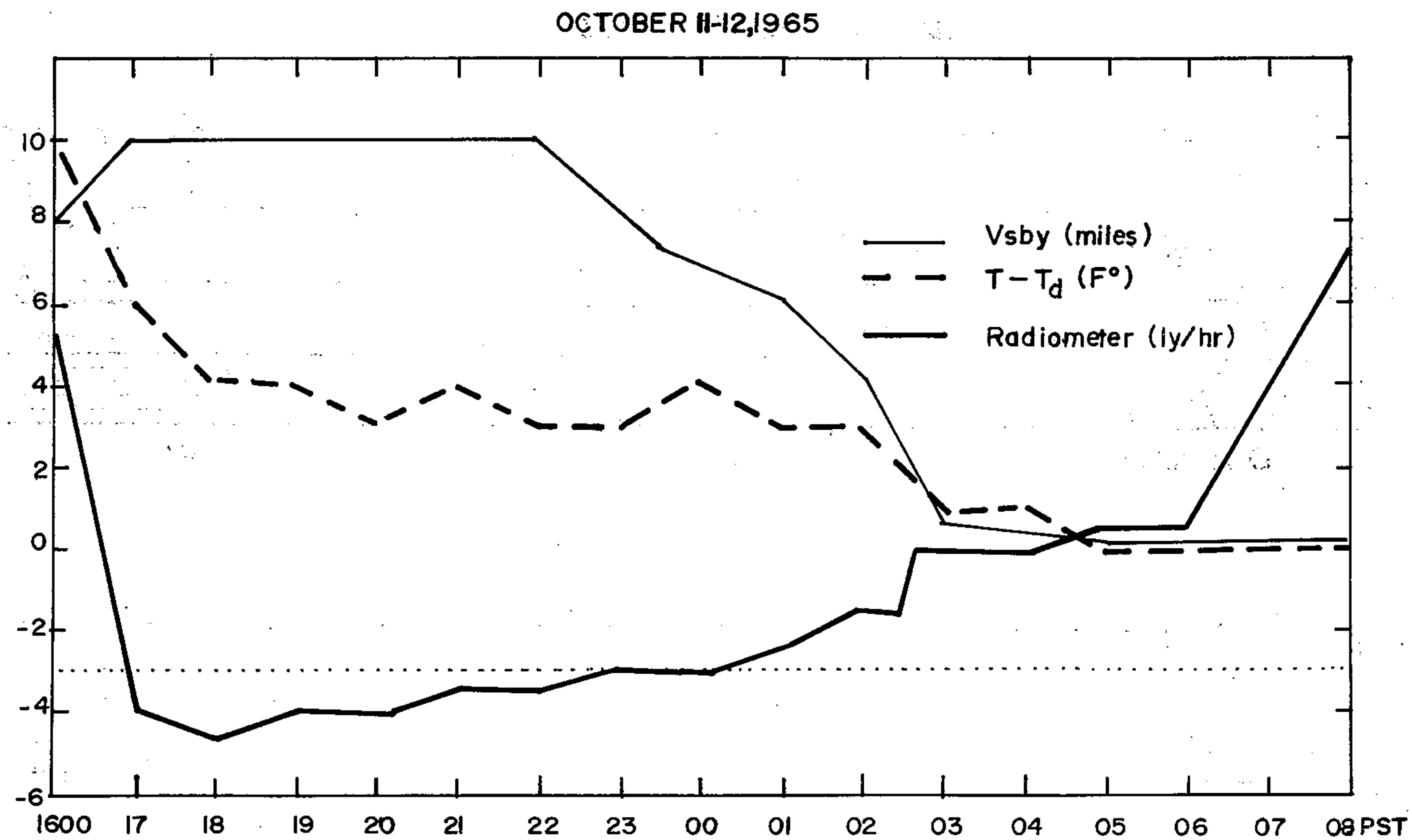


Figure 4 - Net radiation, dew point depression and visibility for Los Angeles, October 11-12, 1965. Vertical scale shows ly/hr, F°, and miles. Radiation scale is greatly expanded from the original trace.

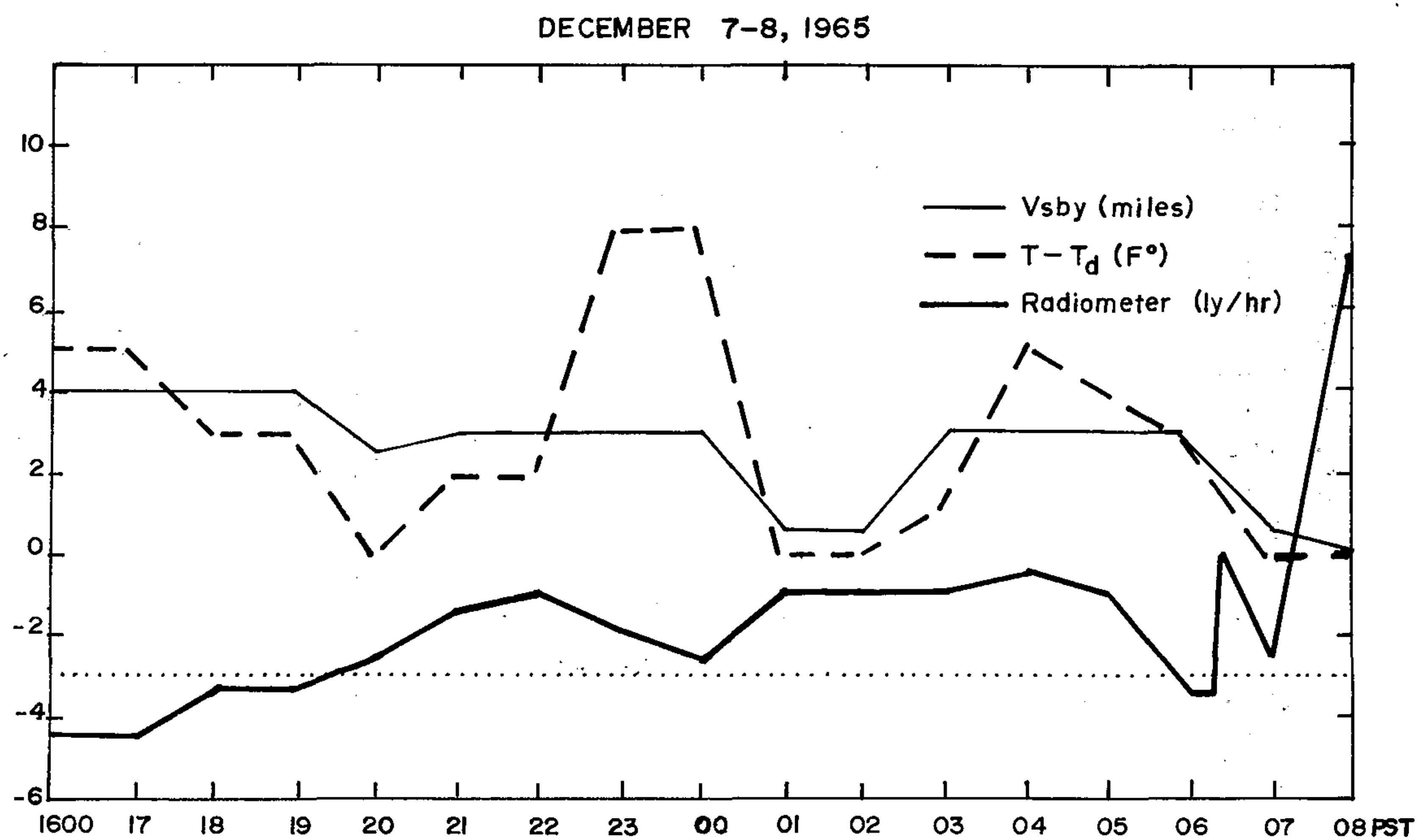


Figure 5 – Net radiation, dew point depression and visibility for Los Angeles, December 7-8, 1965. Vertical scale shows ly/hr, F°, and miles. Radiation scale is greatly expanded from the original trace.

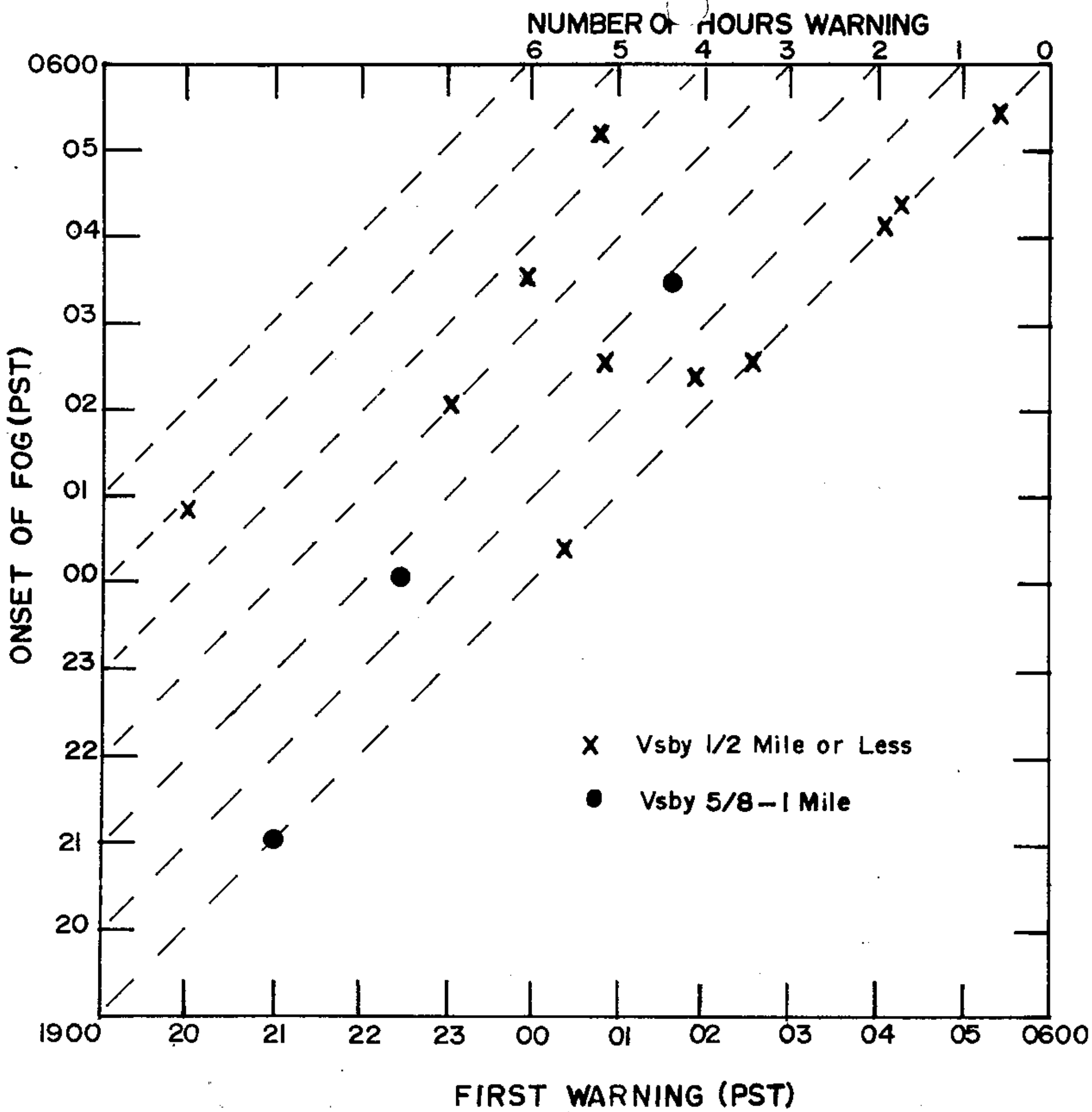


Figure 6 – Lag time between first warning by net radiometer observations and onset of fog at Los Angeles, during period June 1965 through July 1966.